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THE SOVIETS AND THE U-2 PHOTOS– AN HEURISTIC ARGUMENT

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PREFACE

This Memorandum is a contribution to the body of research being done at The RAND Corporation in the field of aerial reconnaissance. It attempts to provide a clearer understanding of Soviet reactions to U.S. reconnaissance activities. It should be of interest to military reconnaissance workers and to students of the political implications of U.S. and Soviet reconnaissance activities, and of arms control and inspection.

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SUMMARY

A current argument regarding Soviet Response to the U-2 flights runs as follows: Although the Soviets knew since 1956 that the U-2 was operating over their territory, presumably on reconnaissance missions, they had no idea of the photographic quality being secured and, therefore, might have thought that the U-2 photos could not reveal significant information. Hence, they may not have chosen to camouflage missile sites and other military installations or to protect them by other measures.

The above argument is invalidated, however, by information and tests easily available to the Soviets from published data on World War II reconnaissance state-of-the-art and on the performance of available equipment. On the basis of the author's knowledge of what was available to the Soviets, this Memorandum argues that the Soviet action or inaction about building, concealing, or protecting military installations in the USSR could not have been based on a mistaken estimate of the efficiency of U-2 photographic operations.

The 1962 Cuba crisis furnishes an additional observation. By this time the Soviets had ample evidence of the photographic quality produced by the U-2. They could not have expected that their missile sites in Cuba would escape detection, given the likelihood of closely spaced surveillance.

CONTENTS

I. INTRODUCTION

There has been much vigorous and open discussion of late about the Soviet military posture. Discussions by highly placed U.S. defense officials have repeatedly emphasized that we have better intelligence now than we had a number of years ago and that the Soviets do not "have" as much as we had thought. It is not simply a matter of curiosity; it is a point central to U.S. policy formulation to be able to arrive at reasonable hypotheses to explain, to understand, and hopefully, to predict both Soviet behavior and Soviet responses to U.S. military programs. It is the purpose of this Memorandum to investigate one aspect of the larger problem: the knowledge of photographic technology open to the Soviets which could have influenced their response to the U-2 flights. Most matters involving the U-2 operations remain both operational and technical mysteries, therefore, understandably making the subject one of curiosity and speculation.

Shortly after May 1, 1960, both Soviets and Americans discovered, for the first time, something about the quality of photography secured in the U-2 operations. Both President Eisenhower and Chairman Khrushchev showed U-2 photographs on television and elsewhere; the photographic quality secured was remarkable, in all meanings of that term.

In Moscow, in December 1960, the author was asked by a prominent Soviet scientist about the kind of film used in the U-2 flights. When asked his reason for the question, the Soviet scientist responded, "They were damn good pictures!" Certain questions arise immediately. Were the Soviets surprised, in the technical sense, or were they simply

astonished by the quality of the photography? What should they have expected? What is the significance of the difference between what they might have expected and what they discovered when they secured samples of this photography for the first time?

II. THE U-2 PHOTOGRAPHS

To this date, not much information has been given out about U-2 operations, making the subject very inviting to conjecture and discussion.

The photograph that President Eisenhower showed publicly in the aftermath of the U-2 incident demonstrated the resolution of line markers in a parking lot.* From the photograph we may take these lines to be about six inches in width; however, the well-known phenomenon wherein long single lines are "resolved" when their width is far less than the resolution of the system makes it debatable that the resolution of the U-2 system is actually six inches. It is far more likely that the actual resolution of the system would be on the order of 1-1½ ft. It can be reasoned that the photograph the President showed was probably not an "average" photograph in the usual sense of the word. Many times in the past it has been the author's task to select an "average" photograph. Most of the time many hundreds of photographs must be viewed before one could be found that demonstrated the quality required of the "average." Assuming that Eisenhower's photo was average, one would think it possible to estimate the range of quality secured in actual operations. In fact, it is almost impossible to do so. Therefore, it is extremely likely that the picture shown by President Eisenhower was unusually good and, hence not entirely representative. (Logically, also, it could be argued that he would prefer to show the world a better-than-average photograph.)

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*For a fuller discussion of the meaning of "resolution" as used here see Ref. 1. An excerpt from that paper is appended.

III. WHAT WAS KNOWN ABOUT THE U.S. RECONNAISSANCE CAPABILITY

What was known to the Soviets about U.S. aerial photographic capability? Following the (now) remote days of World War II (when the United States actually gave the Russians some cameras), there was a flood of technical literature resulting from the war. In addition, the large scale availability of surplus photographic gear and the numerous displays of wartime photography made it possible for anyone to find out our wartime photographic capability. Neither incentive nor a genuine military requirement existed for continuing secrecy in these matters. Research and development agencies, the armed services, commercial firms, organizations and individuals were anxious to get publicity, credit, and of course, increased appropriations for carrying on and extending these highly productive activities. Many of the survey articles referred to in Ref. 1, and especially, in Refs. 2-10, give full accounts of equipment types, installations, and performance levels obtained during World War II. Even research advances were described in a readily available document--the Office of Scientific Research and Development Report, Section 16.1 (Optical Instruments).

The U.S. Air Force exhibit in conjunction with the 1955 Open Skies proposal probably gave the greatest impetus to public recognition of the increase in our reconnaissance capability since World War II. Cameras, photographs, and techniques were displayed in New York and were carefully inspected by most U.N. delegates including, it is reported, the Soviet delegation and staff.

Very briefly, the available information included the following. Both the United States and Great Britain employed lenses of 36- and 40-in. focal length (and of course, many smaller lenses as well) during most of the war. During the course of the war, lenses of 60- and 100-in. focal length were made and tested; occasionally, under special circumstances, they were used operationally. After the war R&D in aerial photography continued and expanded. Even larger lenses were designed, built, tested and flown. Novel cameras and huge panoramic cameras were built, described, and used.* In addition, reports on these developments were given, with both equipment and photographs displayed at several of the annual meetings of the American Society of Photogrammetry between 1948 and 1962.

It is easy to relate ground resolution and photographic quality. The formula for ground resolution, in feet, in terms of the scale of the photograph and its resolution stated in lines/mm is as follows:(2)

$$G = \frac{S}{300\,R}$$

where G is the ground resolution in feet, R the resolution obtained in lines/mm, and S is the scale number of the photograph. For a vertical photograph $S = \frac{H}{F}$, where H is the flying height in feet and F is the focal length in feet. Thus, for a photograph taken at 20,000 ft with a 2-ft focal length lens the scale number S is 10,000.

In World War II, under operational circumstances (which implies rugged field handling), photographic quality was of the order of

*A huge contact print made by the E-1 panoramic camera, is on display in the author's office. This single photograph covering from one horizon to the other, is 13 ft by 18½ in.

10 lines/mm. Occasionally one could obtain 15 lines/mm, and still less often, 20. At the same time the quality obtained in a laboratory--with identical but carefully handled, tuned, and operated equipment--was at least one and one-half or two times better than average field quality. Special films, experimental stabilizing and antivibration mounts, experimental lenses and auxiliary equipment increased performance levels to a high of perhaps 40 lines/mm.

The formula for ground resolution, used with the resolution estimates given above, enables one to calculate the ground resolutions obtained during World War II.

IV. CONSERVATIVE SOVIET EXPECTATIONS

With these remarks as a basis for further discussion, let us make the most conservative estimate of what the Soviets should have expected from the U-2 flights. They should have expected that this aircraft would carry a lens of relatively long focal length, somewhere between 24 and 60 in. They should have anticipated that the camera format would produce a viewing angle of at least 60°, derivable either by panoramic camera techniques or by a fan array of several cameras. They should have expected (as an absolute minimum) performance of the order of 12 to 15 lines (remember that this was a peacetime operation enabling careful handling of the equipment).

A sample calculation can be made. Assume that the focal length was the average of the two extremes suggested earlier (24 in. and 60 in.), that the resolution was no more than 10 lines/mm (wartime routine quality) and that the altitude was 70,000 ft. The scale number S of the photography is then $\frac{70,000}{3.5} = 20,000$. By substituting S = 20,000 into the simple formula given earlier, we get $G = \frac{20,000}{300 \times 10}$ = 6.7 ft. These are conservative numbers.

By the time of the U-2 operations the Soviets had both learned and practiced aerial photography. This remark should not be misunderstood. The burden of this report is concerned with what the Soviets should have known about U.S. state-of-the-art. We didn't teach them about aerial photography; they have been practicing it for many years, and, in fact, claim to have developed it as a military tool before the West did. See, for example, the excellent Soviet text Aerial Photography, by A. I. Shershen, published in Moscow in 1958, and available in English

from the office of Technical Services, U.S. Department of Commerce. This is a first-rate book, and is valuable for both its historical accounts of the development of Soviet aerial photography and as an illustration of the technical level of discussion.

The Soviets could not only have used the very conservative figures above, but could have taken one of their better cameras up to comparable altitudes over areas where they knew the U-2 had flown to see for themselves the results of such photographs. The author's belief is that Soviet style in such matters would have led them to tests, without exclusive dependence on calculations.

V. INTERPRETATION

The question now before us is: If the actual ground resolution obtained by the U-2 were on the order of 6 ft, would the detection capability be less than that obtained at the best performance of about 1 or 1½ ft? The answer cannot be documented here, but must rest upon the author's experience and the examination of many photographs. Briefly, airfields and similar major installations are easily detectable and identifiable at resolutions on the order of six feet. Aircraft can be identified and certainly counted, construction can be accurately evaluated, major industrial installations identified.

Why then the attempt to obtain 1½ ft resolution? The answer is that there is no real upper limit on the resolution required to easily exploit material which is marginal at upper levels. The interpretation problems caused by contrast reduction, variability in atmospheric conditions, and the many other image degrading effects, all force higher resolution requirements. Besides, the problems of technical intelligence, which almost always involve measurements (length, thickness, size, etc.), are such as to require high resolution (i.e., low resolution numbers. One foot resolution is "higher resolution" than is 6 ft). Briefly stated, it is the author's belief that there is nothing which would have remained hidden at 6 ft, which would have been discovered at 1½ ft resolution.

The Soviets must have known this because they have an adequate capability in photography and reconnaissance* and/or they could have checked this experimentally. Further, according to Soviet scientists

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*See Appendix B for Khrushchev's boast about Soviet cameras, and the technical testimony at the Powers trial.

participating in the December 1960 Pugwash meeting in Moscow, the Soviets knew during the previous four years that they were being overflown by the U-2. This point was made to the author and to others, not once but several times. They would have had to make the illogical assumption that the U.S. was engaged in a continuous, dangerous, yet unproductive activity--a possible but highly unlikely event.

Whether the Soviets responded to the U-2 flights by use of concealment or camouflage to "protect" their military and industrial installations, or whether they failed to, is not germane to the argument of this report. The argument herein advanced is that their response (or lack thereof) could not have been based on their comparative ignorance, and hence underestimation, of the quality of the U-2 photography.

VI. CUBAN POSTSCRIPT

The preceding material was written well before the October-November 1962 Cuban crisis. The extensive, intensive and unique use of aerial photography in that affair is well known. The discovery of missile sites in Cuba was made from high-altitude photographs secured from U-2 aircraft. That is the only portion of the reconnaissance effort over Cuba of relevance to this discussion.

The major argument of this report is based on analysis of Soviet expectations before they had access to some U-2 photographs. If the Soviets should have anticipated discovery of military installations of various kinds before they saw the U-2 photographs, they certainly learned nothing to degrade these expectations from analysis of the actual photographs. It follows that they could not have expected to construct missile sites with the extensive clearings and deployment they made (as revealed in the photos released by the U.S. during the public phase of the Cuban crisis), and also counted on remaining undetected and unidentified.

As a directly relevant and conclusive discussion, we might well read what the Soviets said about the U-2 photographs. Appendix B contains statements by N. S. Khrushchev; Appendix C by Professor G. A. Istomin. The latter comes from the record of the Powers trial.

Some American observers may have had doubts or questions about the Soviet estimates of U.S. reconnaissance capabilities before May 1, 1960. Whatever tenuous foundation such doubts rested upon should have been effectively and permanently shattered by the Soviet revelations and opinions about the U-2 photos over the Soviet Union in 1960,

and by the Cuba photos of 1962. The technical testimony at Powers' trial tells what the Soviets themselves were able to see on Powers' photos. This material is included in Appendix C.

Appendix A

EXCERPTS FROM OBSERVATION SATELLITES: PROBLEMS AND PROSPECTS

.....As we have implied, an important parameter in describing the performance of observation systems is resolution. It is measurable, it is fundamental, and it is widely discussed; but its use is difficult and often misunderstood, and its limitations are not generally appreciated.

As used originally by astronomers, "resolution" described the ability of a telescope to separate double stars. As it has come to be applied over the years to photographic systems, resolution refers to the ability of a film or a lens, or a combination of both, to render barely distinguishable a standard pattern consisting of black and white lines. [Ref. 11] When we say the resolution of a system is 10 lines per millimeter, we mean that the pattern whose line-plus-space width is 0.1 mm is barely resolved, that finer patterns are not resolved, and that coarser patterns are more clearly resolved.

There continues to be much justifiable discussion and criticism of the use of this single parameter (resolution) to specify performance, for it fails to describe the character of the resolution at all points other than the last, or threshold value. [Refs. 3-5, 12-16] Nevertheless, it is a convenient measure, useful in making gross comparisons and evaluations. [Ref. 1]

Many factors enter into assessment of the interpretability of an aerial photograph. Resolution is only one. The particular characteristics of the photographic emulsion used, its graininess, granularity, microcontrast performance curve (or transfer function), the transfer function of the optical imaging system--these are but a few of the predominate factors. From the formula for ground resolution, one would expect to obtain the same ground resolution by trading resolution and scale number. Thus, one should expect that 10 lines per millimeter at a scale number of 100,000 should yield the same ground resolution as 100 lines per millimeter at a scale number of 1,000,000. However, this type of reciprocity is never the case in either practice or theory.

Several years ago, an instructive series of photographs was prepared by the Boston University Physical Research Laboratory. The number, size, and detail of these photographs defy any attempt at reproducing them here. Briefly, three excellent aerial photographs of the same

scene were secured at scale numbers of 10,000, 20,000, and 40,000. Ground-resolution targets enabled the assessment of the quality level of each of these photographs as being 40 lines per millimeter.

These three photographs were systematically degraded (control being furnished by an auxiliary resolution target mounted adjacent to the negative) from 40 lines per millimeter to 20, 10, 5, 2.5, and 1 line per millimeter. The process may be suspect at the lower numbers, but is undoubtedly correct down to, say, 5 lines per millimeter. Careful inspection of these photographs demonstrates the point that 10 lines per millimeter at a scale number of 10,000, which yields the same calculated ground resolution as 40 lines per millimeter at 40,000 scale number, actually yields more information than the latter. Examination of photographs like these furnishes more, but similar examples, providing a sound basis and insight into the theory and mechanism which explain this phenomenon.

By and large, if one can trade scale for resolution, one should trade in the direction of lower resolution and smaller scale number. It follows that the larger the image to be rendered the greater the contrast. This is a characteristic of the transfer function of the film. There are great differences in the graininess characteristics of different aerial photographic emulsions, and these affect interpretability much more than they influence resolution. [Ref. 1]

Appendix B

SPEECH BY N. S. KHRUSHCHEV

Fifth Session of Fifth Supreme Soviet of USSR, May 7, 1960, as reported in "No Return for U-2," Foreign Languages Publishing House, Moscow, 1960.

> We are in possession not only of the plane's equipment, but of photographs made over several areas of the USSR. Here are some of them. (N. S. Khrushchev holds up the photographs.)
>
> This is a photograph of an airfield. The two white lines are rows of Soviet fighter planes. And here is a picture of another airfield, also showing planes. We developed all these films ourselves. (Lively animation.)
>
> I pass these pictures to Comrade Lobanov--he can sort them out. (Animation.)
>
> And here are some photographs of petrol depots. It has to be said that the camera used is not bad, the photographs are very clear. (Animation.)
>
> But it has also to be said that our cameras produce better, sharper pictures, so that in this respect we acquired very little.... (Laughter.)

Appendix C

THE TRIAL OF THE U-2

Court proceedings of the case of Francis Gary Powers, heard before the Military Division of the Supreme Court of the USSR, Moscow, August 17, 18, 19, 1960, Translation World Publishers, Chicago, 1960.

From Proceedings of the second day, August 18, 1960, First Session, 10:00 A.M.

PRESIDING JUDGE: Please be seated, Defendant. Expert Tyufilin, submit your conclusions to the Court in writing. I ask that the expert Istomin come forward. Your name?

EXPERT ISTOMIN: Istomin, Gleb Alekseyevich.

PRESIDING JUDGE: Your title?

EXPERT ISTOMIN: Doctor of Technical Sciences. Professor.

PRESIDING JUDGE: Will you present the conclusions of the experts on the photographic equipment of the Lockheed U-2 plane.

EXPERT ISTOMIN: In the course of the investigation of the Powers' case, by decision of the investigating bodies, a commission of experts has made a technical examination of the photographic equipment which was on board the Lockheed U-2 aircraft shot down in the Sverdlovsk area on May 1, 1960.
The commission was given the following parts of the photographic equipment for study: a destroyed air camera magazine with four rolls of aerial film 24 cm. wide, separate destroyed elements of the aerial camera, and two rolls of film 7 cm. wide.
The experts were given the assignment to establish:

1. The tactical and technical data of the air camera installed on board the Lockheed U-2 aircraft.
2. The technical characteristics of the aerial films used.
3. From what altitudes and in what areas of the Soviet Union photographs were taken from the Lockheed U-2 aircraft.
4. The possibilities of using the obtained aerial photographs.

The commission of experts, consisting of G. A. Istomin, Dr. Sc. (Tech.); V. A. Bekunov, M.Sc. (Chem.); V. Y. Mikhailov and V. A. Uvarov, both M.Sc. (Tech.); B. S. Semokhvalov and L. V. Zakurdayev, senior scientific workers; and Col. of the

Engineers V. J. Krovyakov, Col. of the Engineers A. Y. Pogozhev, and Lt. Col. of the Engineers B. G. Kurnakov, officers of the Soviet Army, has examined in detail the submitted parts of the plane's photographic equipment, processed the film, studied and map controlled the obtained aerial photographs and studied the films with the object of determining their technical characteristics.

The commission of experts has drawn up a detailed technical finding. Allow me to dwell on the main materials of the experts' finding.

A study of the remnants of the U-2 photographic equipment enabled the commission to establish that a wide-angle long-focus air camera model "73-B" was installed on this aircraft for aerial reconnaissance photography. The name of the model of the camera is given on several company nameplates fastened to the camera body. The locks of the removable spindles of the film spools carry an inscription showing that they were made in the United States.

For its tactical and technical characteristics the "73-B" model is a reconnaissance air camera and its salient feature is that it is designed to photograph large areas from the air in the course of one flight.

The air camera has a rotating lens for ensuring multi strip photography.

In the course of the flight on May 1, 1960, the air camera was used for seven-strip photography consecutively through seven glass-encased aircraft windows in the skin of the plane. The lens cover was from 160 to 200 km. in width. The camera was loaded with two films, each of which was 24 cm. wide and about 2,000 m. long. The films were placed parallel to the focal plane of the camera so that during each action of the shutter two films were exposed with a total size of 45x45 cm. The supply of film in the camera made it possible to receive about 4,000 paired aerial pictures, i.e., to photograph in the course of the flight on May 1, 1960, a route of about 3,500 km.

The air camera had a lens with a rated focal length of 915 mm; the rated focal length of the lens and the actual focal length of the aerial camera, equal to 944.7 mm, are indicated on the body of the lens.

The camera lens with a sufficiently long focus made it possible to obtain from the high altitudes at which the plane was flying relatively large-scale photographs suitable for the purposes of aerial reconnaissance. The image scale of the pictures obtained over the territory of the USSR on May 1, 1960, was 220-230 metres in one centimetre. On photographs of such a scale it was possible to determine the designation of most industrial and military installations.

The film used in the "73-B" model camera was studied with regard to its photographic characteristics, resolving power, spectral properties, structure, composition of the emulsion layer and the properties of the base.

The film which was on the Lockheed U-2 aircraft possessed high sensitivity and could ensure aerial photography throughout the day. It is a film of a special grade designed for aerial surveys from high altitudes. Compared with the film used in American spy balloons of the 1956 model, the given grade has been improved for a number of specifications essential for high-altitude aerial photographic reconnaissance of military, industrial and topographic objects.

The film from the U-2 aircraft was processed. The negatives obtained after laboratory treatment were identified and map-controlled.

The results of the map control of the negatives showed that aerial photographs were taken from the U-2 on May 1, 1960, over the territory of the USSR along a route passing from an area West of Tashkent to Sverdlovsk.

The route along which photographs were made conforms to the route of flight plotted on the flight map which Powers had.

The altitude at which aerial photographs were taken was determined by the pictures with account of the actual focal length of the camera; according to this determination, the altitude was 20,000-21,000 metres.

Identification of the aerial pictures shows that the latter contain diverse espionage information about objects located along the route of the plane's flight. The aerial photos show large inhabited places, industrial and military installations--factories, plants, electric stations, warehouses, mines, various means of communication, air fields, and anti-aircraft defense means. The aerial photos can be used both for espionage purposes and for specifying topographical maps.

The commission of experts established the following:

1. The 73-B model camera, installed on board the Lockheed U-2 aircraft is a special reconnaissance air camera designed for aerial photography of a large area during high-altitude flights.
2. The film used in the camera installed on board the Lockheed U-2 aircraft is of a special grade designated for aerial photographic reconnaissance of military and topographical objects from high altitudes.
3. The photographing of the territory of the Soviet Union was made from an altitude of about 21,000 metres on a sector running from an area North of the Soviet-Afghan state border, up to the Sverdlovsk area. The route of the flight (judging by the results of map control of the aerial photographs) conforms to the route plotted on the flight map Powers had.

The total supply of film in the camera made it possible to photograph a route of about 3,500 km long, i.e., to photograph a considerable part of the territory of the Soviet Union along the route of the plane's flight.

4. The aerial photographs made contain sufficiently complete and diverse espionage information regarding industrial and military installations located on the photographed territory and can be used both for espionage purposes and for compiling and correcting topographical maps and determining the coordinates of military and topographical objects.

Thus, a study of the remnants of the photographic equipment of the Lockheed U-2 aircraft which violated the state frontier of the USSR on May 1, 1960, and the materials of the aerial photography taken from it, lead to the conclusion about the reconnaissance nature of this equipment and the espionage purposes of the flight by this aircraft.

PRESIDING JUDGE: Do the participants in this court proceeding have any questions to the expert Istomin?

PROCURATOR RUDENKO: No.

DEFENSE COUNSEL GRINEV: The Defense--none.

PRESIDING JUDGE: Defendant Powers, do you have any questions to the expert Istomin?

DEFENDANT POWERS: No.

REFERENCES

1. Katz, A. H., Observation Satellites: Problems and Prospects, The RAND Corporation, P-1707, May 1959; also ASTRONAUTICS, April, June, July, August, September, October, 1960.

2. Katz, A. H., "The Calculus of Scale," Photogrammetric Eng., Vol. 18, No. 1, March 1952, pp. 63-78.

3. Katz, A. H., "Aerial Photographic Equipment and Applications to Reconnaissance," J. Opt. Soc. Am., Vol. 38, No. 1, July 1948, pp. 604-610.

4. Brock, G. C., Physical Aspects of Air Photography, Longmans, Green and Company, New York, 1952.

5. "Optical Image Evaluation," Proceedings of NBS Semicentennial Symposium on Optical Image Evaluation October 1951, National Bureau of Standards Circular 526, April 1954.

6. Katz, A. H., "Air Force Photography," Photogrammetric Eng., Vol. 14, No. 4, December 1948, pp. 584-590.

7. Goddard, W., "New Developments for Aerial Reconnaissance," Photogrammetric Eng., Vol. 15, No. 1, March 1949, pp. 51-72.

8. Katz, A. H., "Height Measurements With the Stereoscopic Continuous Strip Camera," Photogrammetric Eng., Vol. 18, No. 1, March 1952, pp. 53-62.

9. Katz, A. H., "Camera Shutters," J. Opt. Soc. Am., Vol. 34, No. 1, January 1949, pp. 1-22.

10. Leghorn, Col. Richard S., "U.S. Can Photograph Russia From the Air Now," U.S. News and World Report, August 5, 1955, pp.70-75.

11. Photographic Lenses, Mil-Standard 150, U.S. Govt. Printing Office, October 1950.

12. Schade, Otto, "Electro-Optical Characteristics of Television Systems," RCA Review, Vol. 9, No. 1-4, March-December 1948.

13. Higgins, George C. and Robert S. Wolfe, "The Relation of Definition to Sharpness and Resolving Power in a Photographic System," J. Opt. Soc. Am., Vol. 45, No. 2, February 1955.

14. Higgins, George C. and Robert S. Wolfe, "The Role of Resolving Power and Acutance in Photographic Definition," J. SMPTE, Vol. 65, No. 1, January 1956, pp. 26-30.

15. MacDonald, D. E., "Some Considerations of Resolution, Sharpness, and Picture Quality in Technical Photography," PSA J., Vol. 19, No. 5, May 1953, pp. 49-55.

16. MacDonald, D. E., "Resolution as a Measure of Interpretability," Photogrammetric Eng., Vol. 24, No. 1, March 1958, pp. 58-62.

17. Rose, A., "Television Pickup Tubes and the Problem of Vision," Advances in Electronics, Vol. 1, 1948, pp. 131-165.